CHAPTER 22

PROGRESS TOWARDS A SWEDISH REPOSITORY FOR SPENT FUEL

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Abstract. Nuclear power is producing electricity for the benefit of society but is also leaving radioactive residues behind. It is our responsibility to handle these residues in a safe and proper manner. The development of a system for handling spent fuel from nuclear power plants has proceeded in steps. The same is true for the actual construction of facilities and will continue to be the case for the final repository, for spent fuel, and other types of long-lived wastes. The primary objective in constructing the repository will be to isolate and contain the radioactive waste. In case the isolation should fail for some reason, the multibarrier system shall retain and retard the radionuclides that might get in contact with ground water. A repository is now planned to be built in two steps, where the first step would include deposition of about 400 canisters with spent fuel. This first step should be finished about 20 years from now and be followed by an extensive evaluation of the results from not only this particular step but also from the development of alternative routes before deciding on how to proceed. Aspecial facility to encapsulate the spent fuel is also required. Such an encapsulation plant is proposed to be constructed as an extension of the existing interim storage CLAB. Finding a site for the repository is a critical issue in the implementation of any repository. The siting process was started a few years ago and made some progress but is by no means yet completed. It will go on at least into the early part of the next decade. When the present nuclear power plants are about to be shutdown, there should also be facilities in place to take permanent care of the long-lived radioactive residues. Progress in siting will be a prerequisite to success in our responsibility to make progress toward a safe permanent solution of the waste issue.

22.1 INTRODUCTION

Sweden has twelve nuclear power reactors with 10,000 MWe electric capacity. These reactors are producing some 70 TWh per year and from that production arises about 250 tonnes of spent nuclear fuel. Up to 2010, it is estimated that the cumulative amount of fuel will be some 8,000 tonnes (uranium weight). The responsibility for taking care of this fuel rests with the owners of the nuclear power plants in accordance with the principle that ”the producer is responsible”. The owners have given the mission to the Swedish Nuclear Fuel and Waste Management Co. (SKB) to execute this responsibility for them.

The progress of the Swedish waste management programme is closely monitored by the government and by the pertinent authorities in Sweden. According to the law, SKB has to submit a programme for research, development and all other necessary measures in order to be able to handle and finally dispose of the spent fuel and other radioactive wastes arising from the operation of the nuclear power plants. Such a programme must be submitted at three year intervals and is then scrutinized by the authorities and a broad set of reviewers before the government decides on the programme. In the past, SKB has submitted several such programmes (SKB 1986, SKB 1989, SKB 1992, SKB 1995a). The latest programme is still under review by the government.

As the implementation of the programme proceeds and reaches the siting and construction phases, the same authorities will be responsible for evaluation of the safety and giving stepwise permission to proceed towards completion of the system.

22.2 STEPWISE DEVELOPMENT

The development of a system for handling the spent fuel has proceeded in steps. The first steps were taken during the 1970s when a parliamentary committee proposed the construction of a central interim storage facility for spent nuclear fuel and to initiate research for disposal of high level radioactive wastes deep in the crystalline bedrock in Sweden (Aka 1976). The research took a great step forward with the KBS-project which was established in late 1976 in response to a new law. This was the stipulation law, which required that the nuclear power plant owners work out a plan for handling and final disposal of high level waste from spent fuel before the last six reactors of the power programme were allowed to start operation. These plans became known under their abbreviated names KBS-1, KBS-2 and KBS-3 (SKBF 1977, SKBF 1978, SKBF 1983, respectively).

KBS-1 addressed the disposal of vitrified waste from reprocessing, whereas KBS-2 and KBS-3 described the disposal of unreprocessed spent nuclear fuel. All three studies included a period of interim storage before the final disposal; a period of 30 - 40 years was considered appropriate in order to decrease the thermal load on the repository.After about 40 years, the residual decay heat in the fuel will have decreased by about 90 % in comparison with one year old spent fuel. A further equally important consideration in favour of interim storage is the creation of flexibility and buffer capacity in the management system for the spent fuel.

In the 1980s, the Swedish programme was focused on final disposal of the spent fuel without reprocessing. There were several reasons. The nuclear power programme was limited to twelve reactors. The prices for natural uranium and enrichment services stabilized or even decreased, whereas the prices for reprocessing services and Pu-recycle continued to increase. Thus, direct disposal got an economic advantage. The concern for nuclear proliferation, as a consequence of increased handling of plutonium, created a political resistance against reprocessing and Pu-recycle. The development of the breeder slowed down.

Several alternative methods for final disposal of spent fuel in the Swedish crystalline bedrock were studied and evaluated as a part of the broad R&D-programme, which continued based on the KBS-reports. In 1992, SKB concluded that a method similar to the one described in the KBS-3-report would be best suited for use, at least for the first step, in implementation of a deep repository. In general this conclusion was accepted by the authorities although some reviewers considered the choice to be premature.

22.3 STEPWISE CONSTRUCTION

An interim storage facility, CLAB, was constructed in the early 1980s at the Oskarshamn nuclear power plant. It was put in operation in 1985. CLAB has at present a capacity of 5,000 tonnes and can easily be expanded to meet future demands. About 2,300 tonnes of spent fuel was in storage at the beginning of 1996.

Following the evaluation of alternative methods in 1992, SKB decided to start the implementation process for the first steps in building a deep repository for spent nuclear fuel. This comprises the siting and basic design of an encapsulation plant for the fuel and of a deep repository. The first stage of the repository is planned for about 400 canisters or 800 tonnes of fuel and should start operation in 2008 (Fig. 22.1). The encapsulation plant is planned for filling one canister per day.

After the first stage has been completed, a thorough evaluation will be made both of the experience gained from the first stage and from development of other, alternative treatment and disposal methods that have been studied and/or applied in Sweden or elsewhere. The opportunity to change the route or even to retrieve the canisters that have been deposited will be available. This strategy thus provides an approach where irrevocable decisions must not be made until all aspects of the repository implementation have been fully demonstrated.

The implementation of the first stage will also proceed in steps with siting, basic design and supplementary R&D during the 1990s, with construction during the main part of the next decade and the first stage operation and evaluation during the 2010s. The stepwise approach is thus a key element in the planning and implementation for a repository.

22.4 SAFETYAPPROACH FOR A DEEP REPOSITORY

The safety of a deep repository is dependent on the radiotoxicity and on the accessibility of the waste. Both these properties are time functions. Thus, the safety of the repository has to be assessed as a function of time. There will always be a fundamental uncertainty in the prediction of the future behavior of any system and the uncertainty may increase with time. The Swedish Radiation Protection Institute has discussed the influence of the time horizon on the safety assessment and radiation protection (SSI 1995). They conclude that:

- Particularly great attention should be given to describing protection for the period up to closure of the repository and during the first thousand years thereafter, with a special focus on nearby residents.
- The individual dose up to the next ice age, i.e. up to about 10,000 years, should be reported as a best esti-

Figure 22.1. Deep repository showing schematic layout of stage 1 and stage 2.

mate with an estimated margin of error. Environmental protection should be described for the same period of time.

- For the period from the next ice age onward, qualitative assessments should be made of what might happen with the repository, including scenarios taking into account the risk of increased releases.

The safety of a repository is achieved by the application of three principles:

- Level 1 - Isolation. Isolation enables the radionuclides to decay without coming into contact with man and his environment.
- Level 2 - Retardation and retention. If the isolation is broken, the quantity of radionuclides that can be leached and reach the biosphere is limited by:
  - very slow dissolution of the spent fuel;
  - sorption and very slow transport of radionuclides in the near field; and
  - sorption and slow transport of radionuclides in the bedrock.
- Level 3 - Recipient conditions. The transport pathways along which any released radionuclides can reach man are controlled to a great extent by the conditions where the deep groundwater first reaches the biosphere (dilution, water use, land use and other exploitation of natural resources). A favourable recipient means that the radiation dose to man and the environment is limited. The recipient and the transport pathways are, however, influenced by natural changes in the biosphere.

The safety functions at levels 1 and 2 are the most important and the next-most important. They are achieved by means of requirements on the properties and performance of both engineered and natural barriers and on the design of the deep repository. Within the frames otherwise defined, a good safety function at level 3 is also striven for by a suitable placement and configuration of the deep repository.

22.5 DEEP REPOSITORY

The isolation of the spent nuclear fuel from the biosphere is achieved by encapsulating the fuel in a canister with good mechanical strength and very longlived resistance against corrosion. The conceptual design adopted is a copper canister with a steel insert. The copper provides a very good corrosion resistance in the geochemical environment foreseen in a deep repository in Sweden. The steel insert provides the mechanical protection needed. Each canister contains about 2 tonnes of spent fuel. The canisters are placed in deposition holes drilled from the floors of tunnels at about 500 m depth in the crystalline, granitic bedrock (Fig. 22.2). Each can-

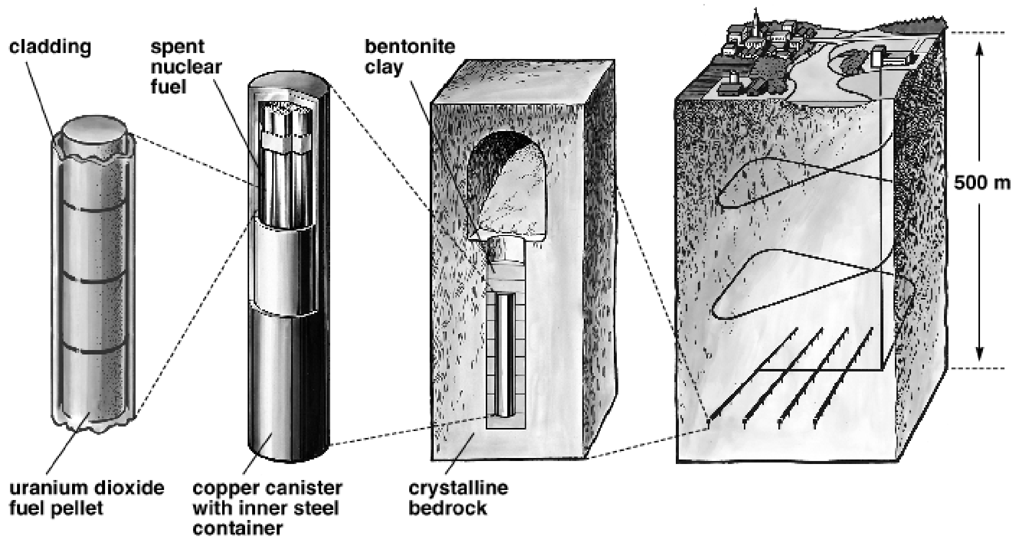

Figure 22.2. Deep repository in accordance with the KBS-3 concept.

ister is surrounded by blocks of compressed bentonite. When the bentonite absorbs water from the surrounding bedrock it will exert an intense swelling pressure and completely fill all void space in the near vicinity of the canister with bentonite clay. The clay barrier will contribute to the isolation by preventing or delaying dissolved corrosive species that may exist in minor amounts in the ground water to reach the canister. The clay will also provide some mechanical protection for the canister.The tunnels will eventually be backfilled by some material like a mixture of crushed rock and bentonite.

Arepository for all spent fuel from the present Swedish programme should have a capacity of about 8,000 tonnes or 4,000 canisters. In addition it should be able to deposit other types of long lived wastes at the same site. This means that the underground facilities will need some 30 - 40 km of tunnels and cover an area of about one km^2. The surface facilities at the repository site will require an area of about 0.2 km^2.

SKB has started the planning work for a deep repository by preparing plant descriptions. These provide examples of possible ways to design the repository with its buildings, land areas, rock caverns, tunnels and shafts. They also contain requirements on, and principles for, the various functions of the repository. To a large extent, the construction and operation of the facility can be based upon experience and proven technology from nuclear installations and underground rock facilities. Special attention is given to: the impact of the excavation work on surrounding rock, methods for preparation and installation of the buffer bentonite blocks, and the technology for backfilling and sealing.

22.6 ENCAPSULATION OF SPENT NUCLEAR FUEL

Another necessary facility where the planning work has started is a plant for encapsulating the spent nuclear fuel. The intention is to expand the existing interim storage facility, CLAB, at Oskarshamn with such a plant. The plant will take fuel assemblies from the underground storage pools, dry them, transfer them to canisters made of copper with a steel insert, change the atmosphere to inert gas, put lids on the canisters and seal the lids by electron beam welding. The quality of the filled and sealed canisters will be inspected by non-destructive examination (NDE) methods - ultrasonic and radiographic - before shipping to the repository.

Each canister will contain 12 BWR fuel assemblies or 4 PWR assemblies. The copper thickness will be about 50 mm and the steel thickness also about 50 mm (Fig. 22.3). The copper thickness shall be enough to prevent corrosion from penetrating the canister during the time when the spent fuel radiotoxicity substantially exceeds what one would find in a rich uranium ore. The combined thickness of steel and copper should be enough to prevent any significant radiolysis of water outside the canister after deposition in wet bentonite clay. The steel insert is designed to withstand the normal mechanical loads that will prevail on the canister in the repository such as hydrostatic pressure and the bentonite swelling

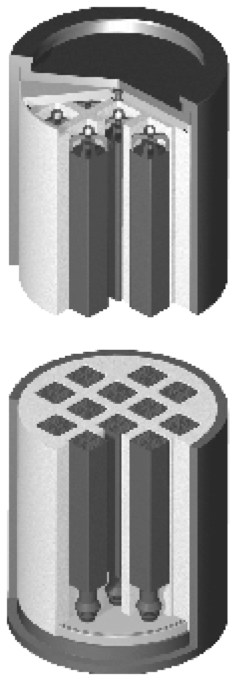

Figure 22.3. Copper canister with steel insert.

pressure. The total weight of a canister with fuel will be about 25 tonnes. In total some 4,000 canisters will be required for the spent fuel arising from the Swedish reactors up to 2010.

The design of the steel insert is still under evaluation. The present reference concept is a cast insert with thick steel walls between each fuel assembly. This gives a good mechanical stability as well as providing adequate protection against criticality in the unlikely case that the canister, at some unspecified future time, should be filled with water.

The fabrication of copper canisters of the size needed is by no means an industrially available technology. The seal welding technology has recently been demonstrated on a laboratory scale in work sponsored by SKB at The Welding Institute in UK. Full scale canisters have also been fabricated on the laboratory scale. In order to make key technology more mature, SKB has decided to create a laboratory for encapsulation technology at the former shipyard in Oskarshamn. This laboratory will be ready sometime during 1997 and will primarily be devoted to further development of the seal-welding process and the NDE-methods.

The design of the encapsulation plant is in progress. The main contractors for the design are BNFL for the key hot cell parts and ABB Atom for the other systems. The work is at present directed towards final specifications for the above mentioned laboratory as well as the development of an Environmental Impact Statement and a Preliminary Safety Report forming a basis for an application for a siting and construction permit. The application is planned for submission in early 1998.

22.7 REPOSITORY SITING

The most crucial part of the development of a deep repository is the siting process. SKB started geological site investigations at an early stage in the programme. Throughout the 1970s and 1980s, so called study sites were investigated at some 10 locations scattered from the southern to the northern part of the country. The investigations included measurements in boreholes as deep as 1000 m, as well as geophysical measurements from the surface. The main conclusion from these site investigations was that there are many places in the Swedish bedrock that provide conditions which are suitable for siting a repository at a depth of about 500 m. This implies that the safety requirements for a site can be met at many places and that factors other than safety can also be decisive in siting.

One such factor of importance is the acceptance by authorities and local residents. After the presentation of the RD&D-programme 92, SKB got in contact with several municipalities in various parts of Sweden. These contacts led to the proposal to start so called feasibility studies for the municipality in order to more clearly define the possibilities and consequences of siting a repository in the municipality. The intent was that the municipality as well as SKB should get a comprehensive set of documentation on which to base any decision of further, more detailed studies. Aprerequesite was that the feasibility study should be based on existing geological data; no drillings and new measurements would be included. The discussions resulted in feasibility studies in Storuman and Malå in northern Sweden, Lappland (Fig.22.4).

The study for Storuman was published in February of 1995, (SKB 1995b) and that for Malå in March 1996 (SKB 1996). In both municipalities, two fairly large areas - 50-100 km^2 - were identified to be of interest for further investigations as potential host formations for a repository. However, in September of 1995, Storuman had a referendum on whether to permit further investigations for a repository site in the municipality, and the outcome was more than 70 % no-votes. This means that

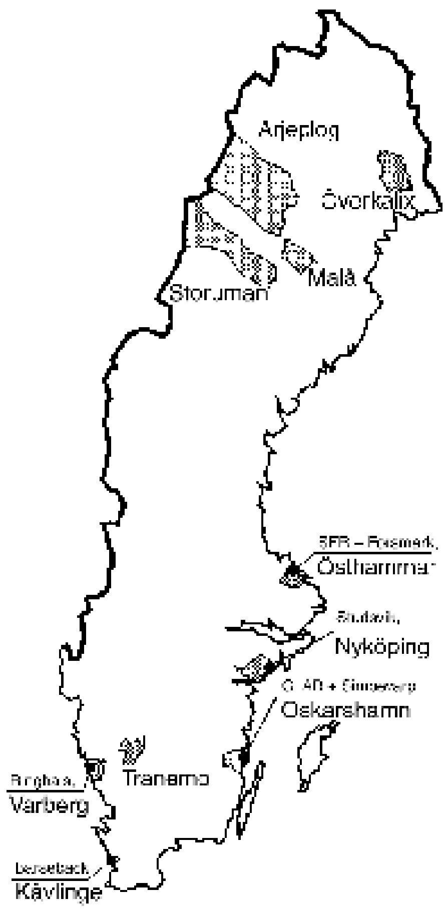

Figure 22.4. Location of some municipalities in Sweden.

SKB’s work at Storuman has ceased. The study in Malå is now being reviewed by the municipality with the help of an independent group of experts.

SKB also performed a general study of five municipalities: Östhammar, Nyköping, Oskarshamn, Kävlinge and Varberg, where nuclear facilities are already located. The conclusion from this study was that there was a clear interest to continue with specific feasibility studies for the three first mentioned municipalities. There was also some interest for a study in Varberg, although the existing geological data for that area are rather meager and must be supplemented. As a result, feasibility studies are now going on in Östhammar and Nyköping whereas the proposal is still being evaluated by Oskarshamn. Varberg has declined a feasibility study.

SKB has also had fairly extensive discussions with three other municipalities: Överkalix, Arjeplog and Tranemo. These have finally resulted in negative answers from the municipalities mainly due to strong local opposition. In a few other cases, the negative answers were given at an early stage.

In 1995 SKB published a General Study '95 (SKB 1995c) which provides background material and gives an overview of some important siting factors on a scale covering the whole of Sweden. One main conclusion from this study is a confirmation of previous observations that it is not feasible to identify interesting areas on such a coarse scale. It is, however, possible to identify some major areas like Gotland, Skåne and the mountain range at the border with Norway where the geological and other conditions are such that it is of less interest to look for a site.

Based on the General Study '95, SKB will continue to study some parts of Sweden on a regional scale in order to identify areas of possible interest. The ambition of SKB is to make feasibility studies of some 5 - 10 municipalities as a basis for selecting at least two sites for investigation including extensive drilling as well as geophysical, geohydrological and geochemical measurements. These investigations will give the necessary data base to seek permits to enable detailed site characterization including construction of tunnels and/or shafts down to repository depths. The government has concluded that such a detailed investigation means that part of the construction of the future repository facility will actually start. This means that a siting permit according to the Act on Management of Natural Resources must also be accompanied by a permit according to the Act on Nuclear Activities.

Critics of SKB claim that the siting process followed by SKB is non-scientific and unsystematic; some even claim that it violates the Swedish environmental protection act. The siting process was, however, outlined in detail in the supplement to RD&D-programme 92, which after a rather extensive review was approved by the authorities and by the government. The fourth paragraph of the environmental protection act says: *For an environmentally hazardous activitity, one shall select such a site that the purpose can be achieved at a minimum of impact and inconvenience and without unreasonable costs.* The process followed by SKB for finding a site for the deep repository is fully in line with this paragraph; the strategy is to find a site where the purpose to construct a safe deep repository can be achieved and then at first hand look at sites where there is some local interest to consider receiving the facility.Thus, one should minimize the inconvenience to areas where there

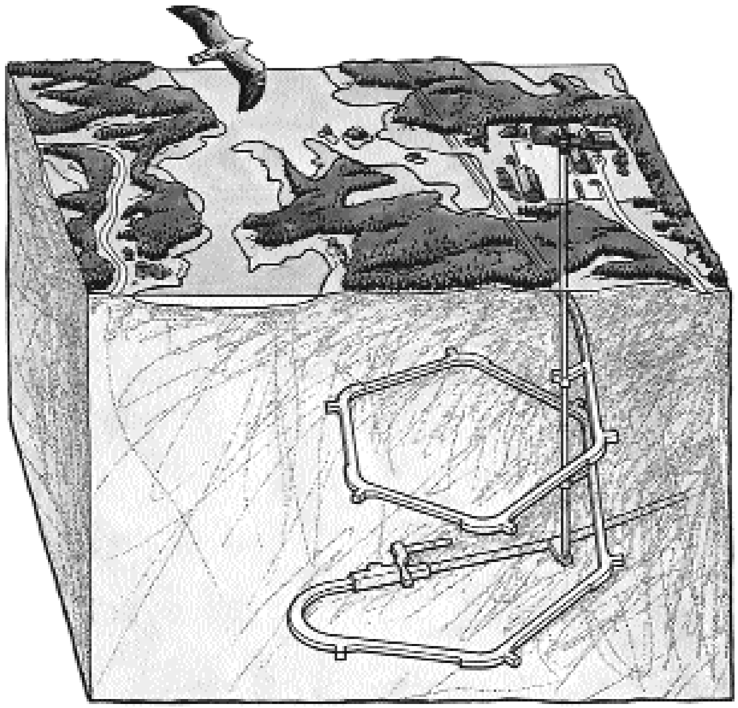

Figure 22.5. General layout of the Äspö hard rock laboratory.

is no such interest. At the same time, the authorities want to have a reasonably broad base for judging that there are no other sites which would obviously be better choices than the one finally selected for an application to construct the repository.

22.8 ÄSPÖ HARD ROCK LABORATORY

In order to prepare for the siting and construction of a deep repository, SKB has built the Äspö Hard Rock Laboratory. The planning of this facility started some 10 years ago in 1986. The work at the laboratory has proceeded in three stages: planning and site investigations, construction, and operations. The first two stages have now been completed and the operational stage has started. A basic objective in the planning of the laboratory was to create a facility for research and development in a realistic and unperturbed environment at a depth planned for the future repository.

The Äspö HRL is designed to meet the requirements on R&D. The underground construction starts with a tunnel from the site of the Oskarshamn nuclear power plant heading north down to about 220 m depth under the island of Äspö. The tunnel then goes down in a spiral with a radius of some 150 m down to 450 m depth. The total length of the tunnel is about 3,600 m. The last 400 m were excavated by a Tunnel Boring Machine (TBM) as opposed to the first part that was drilled and blasted. The cross section of the tunnel is about 25 m^2 (Fig. 22.5).

Overall objectives for the research conducted at Äspö are to:

- increase the scientific understanding of the safety features and function of a repository;
- develop and test technology that will simplify the disposal concept and decrease costs while retaining quality and safety; and
- demonstrate the technology that will be used for disposal of spent fuel and other long-lived wastes.

When the Äspö-project started in the late 1980s, the work program was formulated in several stages. The goal of the first stage was to verify that investigations on the surface and through boreholes from the surface will provide enough data on the important properties related to safety of the bedrock at the repository level. The comprehensive site investigation programme, conducted before the start of construction, was the basis for predictions on geological, geohydrological and geochemical data and behaviour of the rock at depth. These predictions were then compared with observations and measurements performed during the tunnel construction stage. A general conclusion concerning the first stage goal is that the methods available for site investigations are well suited to obtain data and information on the bedrock at a given site. These data can be used to select the proper volume of rock needed for a repository and to make the safety assessment needed for obtaining a permit to construct tunnels and/or shafts for starting detailed site characterization.

The goal of the second stage was to develop the methodology for such detailed site characterization. During the construction of the laboratory, considerable experience has been gained in how the detailed studies of the host rock can be conducted, and a good basis has been laid for the actual work to be made at a repository site in the future.

The other stages were related to improved understanding of the natural barrier - the bedrock - and to a demonstration of the technology to be used in the repository. Some of the tasks addressing these goals have already been performed, whereas others are part of the ongoing experimental and investigation programme at Äspö HRL. A series of Tracer Retention Understanding Experiments (TRUE) is aimed at increasing the knowledge on the capacity of the bedrock to retain and retard the transport of radionuclides in fractured rock. Experimental studies are being carried out to determine how and at what rate the oxygen, present in the repository at closure, is consumed by reactions with the rock. A special borehole laboratory - CHEMLAB - has been developed. It permits chemical experiments to be conducted under repository-like conditions with respect to groundwater composition and pressure. Such experiments will give data to verify models *in-situ* and check the data used to assess the dissolution of radionuclides, the fuel corrosion, the sorption on rock surfaces, the diffusion in buffer materials etc. A full-scale (in-active) prototype repository is planned to be built at Äspö. It will provide the opportunity to simulate all stages in the deposition sequence in a realistic environment. It will also be possible to observe the simulated repository several years in advance of depositing the first (active) canister in the final deep repository.

The work at Äspö has attracted a large international interest, and at present eight foreign organizations from seven countries are participating in the Äspö programme. Several of the experiments are conducted with very active participation by scientists from the foreign participants. This provides a good mechanism for further strengthening the scientific quality of the work and gives all participants access to a broad international forum for discussing the planning, execution, evaluation and interpretation of the experiments.

22.9 CONCLUDING REMARKS

The implementation of a deep repository for spent nuclear fuel is a very lengthy and tedious process in today's society. Considering the time scale intended for the isolation of spent fuel, it is of course still a short time period. In comparison with many other more common projects, however, it is unusual and demanding for all those involved. It extends over several decades and must proceed in steps, where each step requires careful planning. This stepwise progress is a key element. It must be stressed that no step should really be irrevocable; it should always be possible to step back and reconsider and even take another route.

The siting of a deep repository in Sweden is now in progress. To complete this process, efforts will be needed not only from the responsible implementing organization but from all parties involved such as the safety authorities, affected local authorities and political bodies. Building of confidence and trust is a key element in the process. Nuclear power is producing electricity for the benefit of society, but it is also leaving radioactive residues behind. It is our responsibility to handle these residues in a safe and proper manner. When the present nuclear power plants are about to be shut down, there should also be facilities in place to take permanent care of the long-lived radioactive residues. This is the responsibility of our generation which has benefited from the electricity produced. It will be up to the following generations to decide on how to use, extend or change the system we have provided. In this way we can take care of our responsibility without depriving future generations of their possibilities to take their own actions. Considering the existence of long-lived radioactive wastes, a deep repository for such residues will, however, be an asset for society.

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